

occupied by the LFE width and is typically in the range of 3-4, such that the space/time integral of the electric fields experienced by an ion over a full period is equal to zero. The magnitudes of V_1 and V_2 should be sufficiently great to achieve the desired focusing effect detailed below, but not so great as to cause discharge between adjacent electrodes or between electrodes and nearby surfaces. It is believed that a magnitude of 50 to 500 V will satisfy the foregoing criteria.

[0066] Application of the prescribed DC voltages to HFE's **205** and LFE's **210** generates a spatially alternating pattern of high and low field strength regions within the ion transfer channel **115** interior, each region being roughly longitudinally co-extensive with the corresponding electrode. Within each region, the field strength is at or close to zero at the flow centerline and increases with radial distance from the center, so that ions experience an attractive or repulsive radial force that increases in magnitude as the ion approaches the inner surface of the ion transfer tube. The alternating high/low field strength pattern produces ion behavior that is conceptually similar to that occurring in conventional high-field asymmetric ion mobility spectrometry (FAIMS) devices, in which an asymmetric waveform is applied to one electrode of an opposed electrode pair defining an analyzer region (see, e.g., U.S. Pat. No. 7,084,394 to Guevremont et al.)

[0067] FIG. 6 shows the trajectory of a positive ion positioned away from the flow centerline under the influence of the alternating asymmetric electric fields. The ion moves away from inner surface of the ion transfer channel in the high field-strength regions and toward the inner surface in the low field-strength regions (this assumes that the HFE's **205** have a positive voltage applied thereto and the LFE's **210** carry a negative (again, noting that the polarities should be assigned with reference to the smoothed (i.e. averaged over the spatial period) potential distribution along the flow path, as described above), producing a zigzag path.

[0068] As has been described in detail in the FAIMS art, the net movement of an ion in a viscous flow region subjected to alternating high/low fields will be a function of the variation of the ion's mobility with field strength. For A-type ions, for which the ion mobility increases with increasing field strength, the radial distance traveled in the high field-strength portion of the cycle will exceed the radial distance traveled during the low field-strength portion. For the example depicted in FIG. 6 and described above, an A-type ion will exhibit a net radial movement toward the flow centerline, thereby preventing collisions with the ion transfer channel **115** inner surface and consequent neutralization. As the ion approaches the flow centerline, the field strength diminishes substantially, and the ion ceases to experience a strong radial force arising from the electrodes. Conversely, for a C-type ion (for which ion mobility decreases with increasing field strength), the radial distance traveled by an ion in the low field-strength regions will exceed that traveled in the high field-strength regions, producing a net movement toward the ion transfer channel **115** inner surface if the polarities of V_1 and the ion are the same. This behavior may be used to discriminate between A- and C-type ions, since C-type ions will be preferentially destroyed by collisions with the channel wall while the A-type ions will be focused to the flow centerline. If preferential transport of C-type ions is desired, then the polarities of V_1 and V_2 may be switched.

[0069] The above-described technique of providing alternating DC fields may be inadequate to focus ions in regions where gas dynamic forces deflect the ions' trajectory from a

purely longitudinal path or the mean free path becomes long enough (i.e., where collisions with gas atoms or molecules no longer dominate ion motion). For example, gas expansion and acceleration within ion transfer channel **115** due to the pressure differential between the API source **10** at atmospheric pressure and MS1 **80** at high vacuum (<1 mbar) may cause one or more shock waves to be generated within the ion transfer channel interior near its outlet end, thereby sharply deflecting the ions' paths. For electrodes disposed at the distal portions of ion transfer channel **115**, it may be necessary to apply an RF voltage (either with or in place of the DC voltage) to provide sufficient focusing to avoid ion-channel wall interactions. In this case, RF voltages of opposite phases will be applied to adjacent electrodes.

[0070] An alternative approach to suppress shock waves is to differentially pump the conduit **60** (FIG. 1) and this will be described below.

[0071] FIG. 7 depicts an ion focusing/guide structure **300** according to a second embodiment of the invention, which may be utilized to transportions through near-atmospheric or lower pressure regions of a mass spectrometer instrument. At such pressures, ions are "embedded" into gas flow due to high viscous friction and therefore have velocity similar to that of gas flow.

[0072] Generally we consider a flow as viscous as opposed to molecular flow when the mean free path of the ions is small compared to the dimensions of the device. In that case collisions between molecules or between molecules and ions play an important role in transport phenomena.

[0073] For devices according to the invention with a typical diameter of a few millimeters or up to a centimeter and an overall length of a few centimetres or decimeters, and a pressure gradient from approximately atmospheric pressure to pressures of about one hpa, we have viscous flow conditions throughout the inventive device.

[0074] Actually the viscous flow condition of the Knudsen number $K=\lambda/D$ being less than 1 we have viscous flow down to pressures of approx. 1 to 10 pa, depending on the analytes and dimensions (1 pa for small molecules like metabolites in a 1 mm diameter capillary).

[0075] Focusing/guide structure **300** is composed of a first plurality of ring electrodes (hereinafter "first electrodes") **305** interposed in alternating arrangement with a second plurality of ring electrodes (hereinafter "second electrodes") **310**. Adjacent electrodes are electrically isolated from each other by means of a gap or insulating material or layer. In contradistinction to the embodiment of FIG. 5, the first and second electrodes **305** and **310** are of substantially equal widths. The configuration of ring electrodes **305** and **310** is facially similar to that of an RF ring electrode ion guide, which is well-known in the mass spectrometry art. However, rather than applying opposite phases of an RF voltage to adjacent electrodes, focusing/guide structure **300** employs DC voltages of opposite sign and equal magnitude applied to adjacent electrodes. By appropriate selection of the electrode period D relative to the gas (ion) velocity, ions traversing the interior of the guiding/focusing structure experience fields of alternating polarity at a frequency (e.g., on the order of 1 megahertz) that approximates that a conventional RF field. The alternating fields contain and focus ions in much the same manner as does the RF field. Selection of an appropriate DC voltage to be applied to first and second electrodes **305** and **310** will depend on various geometric (electrode inner diameter and width) and operational (gas pressure) parameters; in a typical imple-